Proposal Title: Plant Growth and Development in Lunar Regolith
Responding To: NNH22ZDA001N-SBR: E.9 Space Biology Research Studies
Proposing Organization: Gabriel Putnam (PI), doing-business-as Forsako
Estimated Total Cost: $300,000 (per Table E.9-A. in solicitation)
Estimated Period of Performance: 3 years

a) Study Type, Project Type, and Relevance

Study Type: Plant
Project Type: Plant Research Investigations
Relevance to Research Emphasis: Characterizes the effects that exposure to multiple varieties of lunar simulant has on plant biology, physiology, growth, and development for five crops (lettuce, cabbage, tomatoes, mizuna, kale). Effects of space-relevant radiation, and altered light spectra on these factors will also be considered.

b) Scientific Objectives and Aims

Objective: NASA plans to return to the moon with human habitation on the Artemis III mission by 2026. Further missions plan to build a base camp with habitation for a month. Astronauts living for a month will need food to eat and longer term life support. Further, they will need lower equivalent system mass options to reduce payload. One of the best options for meeting these needs is growing plants locally on the lunar surface. Toward this goal, NASA funded work at the University of Florida has demonstrated germination of *Arabidopsis thaliana* in regolith. However, questions remain about the long term viability of plants grown in regolith, as only a single species in a few samples was germinated, it was not a common food crop, had no long term growth, and no evaluation of the space solar environment. The Long-term goal is to examine the viability of lunar farming by addressing these deficiencies. The objective of this application is evaluate the growth of a variety of plants, in a variety of regolith types corresponding to proposed landing sites, under lunar sun over multi-year timeframes. To accomplish the main objective above, we propose the following specific aims:

Specific Aim 1: Examine feasibility of growing plants in simulated lunar regolith.
Specific Aim 2: Evaluate differences in growth between regolith types from at least two different proposed landing sites
Specific Aim 3: Evaluate effect of small mass soil starters in bulk regolith using tests of plants growing in pure regolith, regolith with small potting soil starters, and soil control.
Specific Aim 4: Evaluate effects of solar illumination and solar wind environment with accurate lunar light spectrum recreation as well as α, β, and γ radiation bombardment.
Specific Aim 5: Evaluate long-term viability of plants through all life-stages: germination, seedling, vegetating, budding, flowing, and ripening with digital monitoring of growth and growth environment.
Specific Aim 6: Examine growth and development differences between multiple species with statistically significant number of trials with at least 50 plants/case, 2+ regolith groups, 3 starter states, 2 radiation states, and 5 food plants for 3000 cases.

c) Potential Impact to NASA's Space Biology Program

The proposed work has potential impact on several regions of the Space Biology Program as illustrated by the Program's own stated goals for *Plant Biology*, *the Plant and Microbial Biology* priorities stated in the "*Recapturing a Future for Space Exploration*" roadmap, and the high priorities targets in "*Midterm Assessment of Implementation of the Decadal Survey*." Specifically, the areas of potential impact are:

<u>Space Biology Program stated Goals</u>

- *Food Production in Space* – Directly addresses the need for food production on the moon with five NASA tested crops using lunar regolith and solar environment.
- *Horticultural Approaches for Sustained Production of Edible Crops* – Tests five crops with previous NASA growth (lettuce, cabbage, tomatoes, mizuna, kale) through all life-stages over multi-year timeframes.

<u>Recapturing a Future for Space Exploration - Plant and Microbial Biology</u>

- *Exploration costs and risks through robust, sustainable, bioregenerative life support (Specifically Emphasis on fresh food first, Trade study for the Moon, Test of lower equivalent system mass life support technology in relevant environment and selection of space-optimized plants)* – Tests five food crops in a simulated lunar environment grown only from seed for low starting mass and using primarily fast-growing, broad leaf crops for the best CO_2 conversion in a life-support system while monitoring the CO_2/O_2 near each of the plant growth groups and farfield CO_2/O_2.
- *Reduce uncertainties about the risks of space radiation to plants (Specifically Expand knowledge of risk using model systems in ground facilities and Develop and test genetic resistance)* – Tests lunar regolith growth of plants using best available ground facility recreation of solar spectrum at lunar surface, lunar daylight cycle, and differences in plant growth with α, β, and γ radiation bombardment on half the crops using commercially available radiation testing sources.

<u>A Midterm Assessment of Implementation of the Decadal Survey</u>

- **P2**: *Plant responses and adaptations to spaceflight ("impact by deep space radiation with Earth analogues")* – Highest priority goal met with accurate lunar illumination and multi-type radiation bombardment of multiple plant species.
- **P3**: *Plant systems for life support* - Highest priority goal met by using primarily fast-growing, broad leaf crops for the best CO_2 conversion in a life-support system
- **CC5**: *Long-term storage of nutrients – Mid level priority (yet specifically called out by Midterm authors)* met by growing five crops with known vitamin and nutrient benefits (kale provides vitamins A, K, B6 and C, calcium, potassium, copper, manganese; lettuce provides A, C, K, iron, calcium; mizuna provides A, C, K, calcium, iron; tomatoes provide C, K, B9, and potassium; and cabbage provides C, K, B6, B9, and manganese)
- **CC8**: *Space radiation risks to humans ("expose plants to cosmic radiation similar to that for exploration missions.")* – Subtopic of Highest priority goal met by exposing plants to continuous α, β, and γ radiation and evaluating differences in development and genetic expression under these conditions.